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ABSTRACT

The "symbol systems approach" to the study of computers in education that is outlined avoids the pitfalls of past media research--particularly research on the effects of television on children's learning and knowledge--and asserts that media can be usefully distinguished in terms of the symbol systems they present and the kinds of symbol-using skills they evoke, afford, or inculcate. Early media research questions are criticized for their naive assumptions, inadequate distinctions, and the researcher's zeal to generate answers rapidly. A summary of the implications of the symbol systems approach suggests that (1) every medium, including the microcomputer, will favor the transmission of certain symbol systems over others and is likely to require and cultivate different representational skills; (2) every medium is biased toward specific kinds of activities applied to its symbol systems, and is likely to cultivate a different set of mental operations; and (3) subjects will bring different expectations to different media. Twenty-four references are listed. (LMM)

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The Computer as Educator:
Lessons from Television Research

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PROJECT ZERO TECHNICAL REPORT

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Abstract

Over the past few decades, a vast number of studies have been carried out on the effects of television on children's learning and knowledge. While some useful information has been obtained from these studies, the accumulation of knowledge has been retarded because of an overly simplified view of the way in which media impact on cognition.

As a new wave of studies of the effects of computers on children commences, there are already signs that some of the same errors are being repeated. In particular, there is a tendency to lump together all examples of the medium, to assume that all effects operate from the medium to the child, and to confound what the medium normally achieves with what it can achieve under optimal circumstances. A new approach to the study of computers in education which avoids these pitfalls is outlined. According to the proposed 'symbol systems approach' media can be usefully distinguished in terms of the symbol systems which they present and the kinds of symbol-using skills which they evoke, afford, or inculcate. Correlatively, an approach in terms of symbol systems underscores the particular mental representations which children bring to any encounter with such media and the ways in which these mental representations may be altered as a result of interactions with the medium.

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The Computer as Educator:
Lessons from Television Research

Euphoria Over a New Medium

The word is out. An exciting new technological medium is on the scene, one that puts its predecessors to shame. The medium has unlimited potential for entertainment as well as for education. It can present almost any kind of information in a variety of formats. It speaks directly to individuals of all ages, backgrounds, and sensibilities. More, it is direct, and dynamic; input from all over the world lies at one's fingertips. There is unlimited choice. And, best of all, from an instructional point of view, the new medium or technology is expected to have profound effects, fostering educational achievements in ways that far exceed past inventions.

Though the euphoria is slightly exaggerated, all readers can recognize the tone which pervades these remarks: We have all heard it many times. Most recently, of course, it has been enunciated with respect to the microcomputer. Indeed, it is being uttered nearly every day, in settings from the local school board to the floor of the United States Congress. What is worth recalling, therefore, is that this leitmotif is a venerable one in American (if not in all of

Western) society. Certainly it has been uttered in the recent past with reference to main-frame computer-based instruction and with reference to television in the slightly more remote past. Who knows, but whether an assiduous historian could not locate similar enthusiasm with reference to earlier media of communication -- to film, radio, blackboards and illustrated primers.

While rhetoric can be inflated to encompass radio, television, and computers as well as any other medium of communication, it is important to stress at the outset some clear differences between computers and "classic" instances of media. To begin with, computers have the potential to be used in many ways which exceed the customary human involvement with communicative media. In the standard communication system with a medium, the user is a relatively passive recipient of prepackaged messages, which are presented in one or another symbolic code. The user must be able to decode the messages but is not generally expected to engage in symbolic encoding. Certainly encounters with a computer include such receipt of information, as for example, when one reads a set of instructions at a terminal. However, in other ways, interaction with a computer is closer to an active communication with another agent (and, until now, that agent was always another person or group of persons). In a computational interaction, the user is expected to be able to use the computer as a tool designed to symbolically

"reshape the world" (Bolter, 1993), thus to make it serve as an extension of the human brain. Moreover, in the extreme case, users may actually be creating their own intellectual products and then manipulate, control, and reshape them as if they were tangible objects.

Despite such differences between computers and other familiar media and technologies, one conclusion seems reasonably clear: Whatever their parallels or differences as information technologies, both classes pose a comparable set of problems for the psychologically oriented educational researcher. Moreover, there is every reason to suppose that researchers bent upon understanding "the psychological effects of computers" will be drawn to at least some of the methods and assumptions characterizing earlier studies of other media, pre-eminently the thousands of television studies. Indeed, Kulik, Kulik and Cohen (1980) have already found 500 studies that compared computer-based instruction (CBI) with conventional teaching in colleges, a striking return to yesteryears' study of TV as compared to non-TV instruction.

It therefore seems opportune to consider what steps have in fact been taken in these earlier investigations of media effects. By so doing, we can determine whether there might be some lessons or cues which could help guide the tidal wave of research on the psychology of computers in education which

is almost certain to inundate us in the next several years. No assumptions pertain to computers, nor that we have already gleaned all the lessons from research on television, nor even that the specific lessons are peculiar to television. At the very least, however, such a review may help to block a few false roads and point to a few promising paths.

Revisiting the Classic Questions in Media Research

Faced with a new medium or technology, most researchers -- and indeed, almost any individual with a psychological bent -- is likely to pose some basic questions. Does the new Medium or new Technology have some Educational Effect upon a Subject drawn from some population of interest? And, indeed, stripped to its bare essentials, this is probably the most fundamental question raised about any innovation by any researcher.

It will be our contention that, so broadly expressed, such a question is unanswerable, if not fundamentally misleading and unproductive. It is possible, however, to refine this question in various ways, so as to increase the chances that it can be informatively answered. A more sophisticated version of the question will probe instead the various kinds of psychological effects which might be attained under certain conditions or from certain features and the extent to which these effects might transfer. Even

this version of the question proves circumscribed, however. In our view, only when one focuses on the kinds of symbolic information presented by a medium, on the learning activities it affords, and the ways in which that information or activity impacts upon the cognitive repertoire of a subject, can the operations of a technological medium be elucidated. We believe that a symbol system position provides a promising framework for conceptualizing and designing research on the psychological and educational implications of computer use. Following our review of earlier efforts to elucidate the effects of television, therefore, we will turn to some implications of this "symbol system" position.

The "does it teach better than..." question dominated the field of media research for decades. But the question of whether the instructional use of a medium such as TV (or a computer) yields better learning results than conventional instruction is based on the implicit assumption that there is a uniform Medium called TV and another which can be identified as "conventional instruction." However, the wisdom of hindsight has taught media researchers that the uniform entity called "television" can hardly ever be postulated. One can speak of "television" (or for that matter -- "computers") as a more or less uniform class of events only in some psychological respects and for some purposes for which within-medium differences are irrelevant.

Only in selected cases is it possible to ignore the cognitive differences between, say, at-home viewing of Sesame Street and in-class viewing of How the Blood Clots, between scripting a show and viewing one, between playing computer games and programming, or between a burned-out and a brilliant teacher. One case is when one studies the effects of elements that are or could be commonly shared by all medium-- or instructional -- variants: How does TV's pictoriality affect, say, children's imagery? The second case is when the effects of the whole class, regardless of variations, are examined: What do children come to expect or take away from school after viewing such or another quantity of TV over so and so many years?

The implicit assumption underlying such questions is that the TV qualities which are expected to affect the viewers are sufficiently omnipresent to render the various TV versions as inconsequential. But such an assumption turns out to be unwarranted once instructional usages and learning outcomes are considered. For the variants of TV, of computer use, or of "conventional instruction" are anything but inconsequential. Imagine the perfect experiment in which researchers compare TV and conventional instruction, holding everything else constant. In this hypothetically perfect experiment, as Mielke (1968) described it, a teacher would lecture to students randomly assigned to one class (no interaction with teacher allowed!) while another class would

watch the same teacher at the same time, on a TV screen in an adjacent room. Not many learning differences between the two classes would emerge, as indeed hardly any emerged from the many studies of this kind. Even if differences would have been found, how could they be explained? For the only operating variable would be the mode of transmitting the very same information by means of the same symbolic carriers.

Was this what the researchers had initially in mind? Obviously not. They wanted to compare "television" with "conventional" instruction, naively assuming that it is "the medium" rather than some specific attribute or quality in it that affects learning. But stripping the Medium down to its technological bare bones (the experiment wouldn't be perfect otherwise) affects nothing in and of itself.

Recent meta-analyses of computer-based instruction (CBI) suggest, unfortunately, that the same kind of naivete is implicit in many recent CBI-conventional teaching comparisons. Kulik et al (1980) found that whereas CBI had an average effect size of .51 SD when different teachers taught the CBI and "conventional" classes, it decreased to .13 when the perfect experiment was approximated, i.e. when the same teacher taught both versions. When everything else is indeed held constant save "the Medium," not much of an effect can become observable.

Underlying the TV-vs.-conventional instruction question as well as other typical questions was another implicit assumption, according to which the medium should be better (or worse) for all learners. The possibility that technologically-based mediated instruction may benefit some learners while inhibiting the learning of others was initially ignored. Also the search for TV's more general effects on, say, reading ability, aggressive behavior, and the like, started out (much as computer research does today) by assuming more or less uniform effects.

That this assumption is naive has been born out, first, by the many Aptitude-Treatment-Interaction (ATI) findings which suggested that effects can cancel each other out when averaged across individuals, ages, cultures or contexts. More recent observations that individuals approach the same stimulus and perform the same activity in radically different ways, have further rendered that assumption unwarranted. Thus, such questions as "What do children learn from TV?," "Does TV exposure adversely affect SAT scores?," "Does TV make youngsters become more aggressive?," or "Does TV teach physics better than an alternative?" have turned out to be naive, if not outright nonsensical ones.

The Medium-vs.-conventional instruction question has its place, of course. It is an indispensable question when the worthwhileness of a particular program or package needs to be

assessed, or when practical decisions are to be made. But for the purpose of gaining better insights into the psychological nature and instructional potentialities of a medium or a technology, this research formulation proves of little use. Indeed, it is highly questionable whether any lesson learned from the ways in which computer based instruction (the computer as electronic workbook) affects learning can be applied to other uses of computers: as a tool (as in word processing), as simulator, or as a programming tool. Seen in this light, the common denominator - "computer" - is the wrong denominator. As we argue later, it is not the technological medium but the mental operations afforded by its symbol systems and activities which can make a crucial difference.

Having learned these lessons, media researchers replaced the search for average positive or negative effects of "the Medium" with more refined questions that focussed on specific salient media attributes and qualities. Typical questions in this vein probed: "Does the depiction of movement enhance comprehension?" "Does the computerized manipulation of a model's variables facilitate the comprehension of gradients and absolute values?" The same type of question embedded in out-of-school contexts led many a researcher to ask whether television's depiction of pro-social behavior affects youngsters as much as the depiction of aggression, or, say, whether the medium's depiction of minorities affects

childrens' outlooks and attitudes towards them.

These questions assume that inherent TV qualities are addressed rather than unessential correlates and byproducts. They assume that observed effects can in effect be laid at the knob of the medium. But one may well ask whether the large quantity of violence presented on TV is an attribute of the medium. It might well be that 20-30 hours of weekly exposure to violent contents on any medium would yield similar results, thus underscoring that depiction of violence is not really an inherent quality of TV (Gardner, 1982). Wright and Huston (1983) report findings showing that some of the arousing and appealing effects of televised violence result from the "hyped" nature of the medium's formal features that typically accompany violent contents, but not from the content itself. Violent contents are apparently typical of American TV, but not as defining an attribute of the medium as its formal features that constitute "hype." Today, with the benefit of hindsight, we know that the effects of televised depictions of violence must be compared to the effects of the same amount of, say, printed descriptions of the same contents, if insights into TV's unique import are to be obtained. Those who would attribute the effects of learning a programming language to a computer -- rather than to the learning of any systematic procedure -- would do well to bear this lesson in mind.

The desire to study the pedagogical effects of TV's unique features, whatever they are, leads, however, to yet further complications. In their light, even the refined question of "What Educational Effect does the unique quality have on a Subject" turns out to be rather simpleminded. By studying some unique features (e.g. the ability to algebraically manipulate and control the values in an open-ended computer program), one implicitly assumes that they have unique cognitive effects (learners take informed risks and make conjectures), which in turn contribute to the attainment of the desired learning outcomes. This assumption is naive on at least one account. There is no necessary one-to-one correspondence between what a feature or activity affords or potentially affects and the way this feature is processed or the way the activity is carried out in actuality. Thus while instruction in LOGO may be designed to enhance conditional reasoning, one cannot simply assume that this effect will be forthcoming (see Seidman, 1983).

Not only do individual differences of ability and prior knowledge play a crucial role in determining how learners process a televised feature or carry out a computer-afforded activity; much also depends on how individuals tend to or choose to process the information, or execute the afforded activity. Motivation, perception of task, preferred learning strategy, and the like, appear to play a crucial role.

Consider some representative findings. Children choose to attend to certain TV features according to the latter's expected comprehensibility (Anderson and Lorch, 1983). Children's general beliefs about the nature of the medium and its processing demands influence the amount of mental effort ("depth", "mindfulness") they expend in processing (Salomon, 1983). Whereas certain TV features can activate specific processing skills, the extent to which the skills are mobilized and applied in actuality depends on the learners' perceptions of what it is they are to do with the material (Salomon & Leigh, in press). Youngsters turn to learn from TV when it provides them with information concerning a decision they have to make or an action they have to take, and particularly in cases where preferred interpersonal sources fail to provide such information (Hornik, Gonzalez, & Gould, 1980). It is the youngsters' active search for information that makes them learn something from TV, not the continuous bombardment of nominal stimuli. As Singer and Singer (1983) conclude -- "sheer exposure to television may not benefit one in making sense of the medium" (p. 830).

Put directly, the Subject can affect the experience of the Medium, as well as vice versa. The questions of a medium's short- or long-term effects, refined as they may have become, turned out to deal with only half the story; the other half -- pertaining to viewers' or users' active choice to become involved, to process the information more deeply,

to construe new meanings -- remains to be written.

This issue proves of particular relevance to the study of those computer activities where the learner is assumed to exercise significant control over the material. As Chanowitz and Langer (1980) argue, there are distinguishable ways in which one can go through (or be put through) the motions of control. One can go through them quite mindlessly, relying on previously made distinctions, and seeking perhaps to show good performance (Dweck and Bempechant, 1983); or one can go through them in a more mindful exploratory manner with an intent to reach higher levels of mastery, and hoping to effect new distinctions and to generate new hypotheses. The behaviors may look alike, but the way control is experienced in both is quite different, and hence may lead to entirely different learning outcomes.

The dangers of overlooking how learners actually handle a program may be particularly pronounced in the computational realm. Studying the effects of a computer feature labeled "control over the input of mathematical values" assumes close correspondence between "input" and cognitive activity; this may be an unwarranted assumption. While open-ended computer programs such as LOGO may afford learners with the experience of more mindful control, there is no assurance that the majority of children won't use the turtle to create more or less impressive graphics or just to "fool around" or "play

games": in these instances, they would remain mindless of the underlying math which the program allows them to discover (e.g., Pea & Kurland, in press).

Considerations of what learners actually do, how they process the information, go about solving a problem, or try to figure out a rule (if figuring it out is what they really do!) throw new light on still another commonly raised question: "What does feature x (a mode of presentation, a particular activity) teach?" The problem with this kind of question is that it fails to distinguish between what a feature teaches typically, and what it can be made to teach.

The question concerning typical use pertains to the way the feature is processed, understood, attended to, or manipulated as it is "naturally" encountered. For example, how do children go about using a word processor? What is attended to in a magazine-formatted TV show when compared with a more continuous version? An alternative way is to regard the feature as a potentiality in want of realization, a capability to be capitalized upon. Thus, one asks whether a particular TV formal feature can be made to affect viewers' mental skill mastery under favorable conditions even when that is not the way it typically affects them under ordinary circumstances. Similarly, one may ask what effects using word processing can be made to have as a result of well designed and intensive training in its use.

There is a crucial difference between the two kinds of questions. The "How does it affect them 'naturally'" question treats the person-technology interaction as a natural given, providing the opportunity to explore new aspects of cognitive development, learning, human interaction, and information processing. Indeed, much has been learned about the way children learn to handle TV (e.g., Kelly and Gardner 1981), and much can be learned about cognitive development by observing the ways in which children go about carrying out different kinds of computer activities (Sheingold et al, 1983). But this approach has its limitations; knowing how children typically utilize (or fail to utilize) a word processor tells us little about the way it could be made to be utilized more effectively if certain of its unique features were capitalized upon in deliberate ways.

The "let's-see-how-far-we-can-go" question is more educationally geared, showing less respect for the world "as it happens to be," and asking what specific technological elements can be made to do if particular conditions are met. Salomon (1979) designed TV segments which heavily utilized such features as zooms, changed points of view and particle assembly, to allow children to imitate the features and use them subsequently as 'mental tools'. The point was not to show that TV typically affects skill mastery through such features, because typical shows are not designed to have such

effects. Rather, he wanted to see whether such features can be made to realize their skill-cultivating potential. But this kind of question also has its limitations. While one may thereby determine how much could be learned from a program if some of its elements were capitalized upon, one does not thereby determine the way the program is typically handled under normal conditions.

What, then, of the question "What effect does a Medium have on a Subject?" Unless one is clear whether the question is addressed at the Medium's typical effects or at its potential ones, it is unilluminatingly vague. For the way a technologically afforded mode of presentation or activity is typically handled is not the way it can be made to be handled; and its typical effects, of interest mainly to researchers of typical behavior and development, are not the same as the effects it can be made to have, an issue which may (and perhaps should) be closer to the hearts of psychologically-inclined instructional researchers.

Many of the media research questions whose underlying assumptions and distinctions one can (and we do) question, could be improved upon, as indeed they were. However, there has been one major assumption underlying the general style of research on media in education, the naiveté of which led to costly and irreversible research omissions. The assumption has been that short-term, often single-shot studies of media

exposure effects, could tell us something of importance about the long range, accumulative effects of media. As it turns out, such studies told us very little, and lamentably, in the absence of an appropriate no-TV population, it is now too late to correct the error. While it would be expensive and difficult to mount the research program, there is in principle no reason why we could not undertake today cross-sectional and longitudinal studies of the long-term effects of various kinds of involvement with computers. Failure to undertake such studies may lead in the future to the possibly unwarranted attribution of many educational and social ailments to the introduction of computers, as has happened in our own time in the case of television.

The domination of short-term effect studies limited our understanding of media's effects not only along the temporal dimension, but along the dimension of transfer as well. Numerous claims have been made with respect to TV's widely transferring effects on one's general world outlook ("TV drama makes you believe in a scary world"), human interaction tendencies ("kids become used to one-way communication"), cognitive activity ("it makes them have short attention spans" or "lazy-minded"), general knowledge ("no sense of the past"), and mastery of specific mental skills ("kids learn to think in terms of TV's symbolic forms"). Some of these claims have been empirically examined under mainly experimental conditions and were found to have

some validity.

From these experiments one learns that transfer, even if limited, is perhaps possible. They do not show, however, that transfer is probable; thus one is still unclear whether heavy exposure to TV (analogous to, say, much engagement in computer programming) has any lasting effects that transfer to new contents, situations, or activities. However, it is precisely these lasting transfer-effects that are said to be the major contribution of computers, and, indeed, their main educational justification. As Perkins (1983) correctly comments, "One does not teach through video games so that learners from then on can play those video games even better! The point ... is to achieve transfer beyond the instructional context. The algebra skills learned through gaming are to be applied to physics or economics." Clearly, given the great interest in and ballyhoo about computer's educational effects, the issue of far transfer will be even more critical in the years ahead.

We have sought to show that many of the early media research questions that appeared so sensible at first, turned out to be far less so in view of naive assumptions, inadequate distinctions, and the researchers' understandable zeal to generate answers rapidly. It needs to be said, though, that prior research on television serves a crucial function: Only in hindsight, when research on the

instructional effects of media can be examined with the benefit of time perspective, can important lessons be learned and transferred to the study of new technologies. To these we turn next.

An Approach in Terms of Symbol Systems

In retrospect, one of the most striking aspects of the early work on the effects of television-- an aspect which is (unfortunately) widespread in educational psychological research-- was its atheoretical quality. Most of the research was devised in the absence of any theoretical framework. And, if a framework were implicitly present, it was the uncritical "mechanical" or "engineering approach" sketched above: How does Medium affect Subject?

With time, it became evident that the results did not speak for themselves and it would be useful to adopt some kind of theoretical framework. Under those circumstances, however, researchers were frequently tempted to embrace the other extreme -- to take an already existing framework, usually one borrowed from mainstream cognitive or developmental psychology, and simply impose it willy-nilly on television-centered research. Thus any number of studies simply applied social learning theory, Piagetian theory, or psychoanalytic theory, with little thought about how these theories might be modulated, or even rendered irrelevant, in

the context of children and television.

More recently, many researchers in TV and computers alike have been attracted to a theory which seems closer to home: information-processing psychology, which itself is derived in significant measure from the operation of computers. According to the precepts of the information-processing perspective, the cognizer is analogized to a computer; it is then assumed that he or she receives information, transforms or processes it in various ways (which can be traced on a microsecond-by-microsecond basis) and then issues forth some kind of output. While it may be comforting to explain an individual's involvement with the computer in terms of a theory itself derived from the computer and simulable on a computer, the information processing approach has yet to provide useful leads into the study of media and technology.

It would be disingenuous to claim that we do not have our own theoretical axe to grind. In our view (Salomon, 1979; Gardner, 1979, 1983) the 'symbol system' approach proves particularly appropriate for research on media and technologies because, unlike its competitors, it has been developed specifically to deal with the effects of media on users, as well as the effects of users on the media. Indeed, we believe that symbol systems constitute the very essence of mediated presentations and of activities of the kinds

afforded by computers. While this pedigree does not in itself guarantee its appropriateness for research on television, let alone for research on computers, we believe it is more congenial to the issues which engaged researchers in the areas of media and technology.

At the base of a symbol system approach is the assumption that mental representations, or models, and the operations performed on them, constitute the core of cognition. Rather than being part of the individual's native equipment, however, these representations are assumed to develop as a consequence of the individual's continual interaction with the meaning systems which exist in his or her culture (Vygotsky, 1978).

Accordingly, the symbol system approach commences with an analysis of the ways in which information may be encoded in the external world -- including the media and technology which permeate a culture. The approach takes into account the basic mental apparatus with which humans initially encode various symbols and symbolic messages, and the ways in which incipient cognitive skills are enhanced, supplemented, transformed, and/or constructed as a result of extensive contact with, and manipulation of, such symbolic vehicles. Thus the approach invites a consideration of the multitudinous ways in which the individual's cognitive apparatus operates with, and is operated upon by his or her

symbolic environment. Ultimately, we claim that this perspective offers a set of dimensions which can be applied to the range of information media and technologies, allowing researchers to interrelate such diverse technologies as TV programs, wordprocessors, computer graphics, abacus, and spreadsheets. In the absences of such a set of common dimensions that can be explicated in psychological terms, each technology and each novel variant will require its independent study.

According to the symbol system approach, individuals have the potential to gain literacy with any number of symbolic elements, as well as sets of symbolic elements, which have been organized into structured systems. Thus in our culture individuals have the options to become literate with words (and languages), with graphic depictions (and filmic languages), with musical tones (and musical styles), with gestures (and modes of pantomime), with numbers (and mathematical systems), as well as numerous others symbolic codes. Ordinarily, these entities are first encountered in a relatively direct form: one hears (and learns) the languages spoken by one's family, one decodes the pictures in one's home, the gestures of one's siblings, the numbers of one's pre-school teacher. But increasingly within our own culture, these symbolic vehicles are encountered via one or another medium; and thus a young individual will frequently (if not typically) encounter, even actively manipulate symbolic

systems through media and technologies such as radio, television, movies, or a home microcomputer.

Computers share with other media the potential for transmitting symbolic messages which users have to decode, while adding to this function the potentials for the manipulation of symbolic elements and for the actual design of coded messages, and communicational potentials which heretofore occurred only with other human agents. Seen in this way, computers afford the whole range of symbol system utilization: they present coded information, as in CBI, allowing a modicum of learner-control; they afford the active, disciplined, manipulation of coded information as in word processing; and they serve as a tool with which specific kinds of coded messages can be constructed during ongoing interaction (programming). But various uses of computers can also highlight or short-circuit specific functions: for example, the rules of programming prohibit the use of language for expressive purposes and, at least for the moment, demand rule governed explicit language commands; possibly as a result, they short-circuit emotional uses of language while inculcating or encouraging various kinds of logical planning.

As described so far, symbol systems are 'external' entities: systems which can be observed and described and

which have a material existence in the physical world. But this is only one half of the story. Symbol systems and their modes of manipulation only acquire psychological relevance to the extent that they have (or acquire) some kind of 'internal representation' in the mind of the subject (Salomon, 1979). Researchers differ on the exact form which these symbol encoding and decoding skills might take (Anderson, 1983; Fodor, 1975; Newell and Simon 1972). But what is important to stress is that there must be some 'internal symbol system' and its associated cognitive operations if processing and manipulation of the publicly available symbol system is to occur. This is what facility in a symbol system is all about. All the programming languages will come to nought in the absence of mental representations of their key elements and operations. Indeed, in this day much of development, and much of education, consists of a process of attaining competence in the encoding and decoding of various symbolic systems; in acquiring 'internal' symbol systems or mental representation to deal with diverse external symbol systems.

In what manner do the various media exert their impact on the process of attaining facility in the various symbol systems? Two possible mechanisms follow from the symbol system approach: Information pick-up biases, and activity biases. Intuitively, it could be assumed that the various media through which, say, a story is presented are invisible: A story is a story, after all. But in fact it turns out that

each of these media does exhibit biases, or, to put it alternatively, encourages a characteristic pattern of pick-up by children who are employing the medium. Thus it has been observed (e.g. Meringoff, 1980) that, even in the case of 'the same story,' television tends to highlight the action properties of a narrative, picture books call attention to the figurative language, and radio foregrounds the sound effects. Children's cognitive biases - some less obvious than others - come to parallel these media biases. Viewers of a television story are more likely to place the story in a circumscribed spatial-temporal framework and to draw inferences from the information provided in the story. In contrast, children who encounter the "same" narrative in a story-book format are more likely to attribute to it a more expansive temporal-spatial framework and to draw on their own experiences in making inferences.

Another way in which media impinge on the process of acquiring symbolic facility is through activity biases. While different media (e.g. typewriter and word processor) may employ the same symbol system (language), require the same skills (writing) and be used for the same general purpose (to compose an essay), each may afford and constrain different ways of manipulating the symbol system. The resultant cognitive operations may differ accordingly. More specifically, the activities associated with, say, word processing are determined jointly by the requirements of

writing in a natural language and by the operational rules of a computer-as-tool-for-writing. To the extent that the latter affords qualitatively different operations from those afforded by the typewriter, and to the extent that learners actually and mindfully engage in these operations, to that extent can we expect the computer's activity-bias to become reflected in a cognitive operational bias.

Three lessons follow from this line of argument. First of all, every medium -- including a microcomputer -- will favor the transmission of certain symbol systems over others, and thus is likely to call upon and cultivate different representational skills. Second, every medium is biased toward specific kinds of activities applied to its symbol systems, and thus is likely to cultivate a different set of mental operations. Finally, and relatedly, subjects will bring different expectations to different media: Thus a child approaching a microcomputer will be in a more 'interactive set' than a child approaching a typewriter or a television set.

Given the alternative symbolic menus of various media, a set of educational implications also follows. For instance, some symbolic features carry out overtly the very operations learners should ordinarily employ on their own, but can't; these supplanted operations can eventually become internalized to be used as 'mental tools'. Furthermore, the

outcomes of these operations can also be "internally" anticipated. For instance, subjects become able to envision how a model would look as a consequence of changing its parameters, thus foreseeing what bugs they are going to encounter when programming, or what new input values would be needed, when responding to a packaged program.

To summarize, then, media differ instructively in the kinds of symbol systems which they characteristically present, in the means by which they transmit these symbol systems, and in the activities they afford. Users, in turn, will have different symbolic capacities and operations activated, may become biased to expect certain symbolic presentations rather than others, and will cultivate a different set of symbolic skills and operations, depending upon the diet and choice points characteristically encountered in a given medium. In our view, an examination focussed on the symbolic systems presented and cultivated by a medium and the symbol-system activities afforded by it is far more likely to reveal their genuine and potential educational effects than any mere consideration of the medium's technological aspects per se.

Applications to Computers

How might this set of considerations illuminate the child's encounters with the world of computers, for example,

with a personal microcomputer? Even casual consideration reveals that the computer stands at the high end of complexity, in terms of the variety of symbolic systems which it can present, the multiplicity of ways in which these systems can be presented, and the raft of symbolic skills which it can cultivate, transform, or supplant in the human user. To begin with, one can designate the kinds of symbolic codes necessary simply for the proper use of or communication with a computer: These would apparently include the mastery of ordinary (natural) language as well as whatever literate linguistic and mathematical abilities appear to "constitute" or to be required by a programming language (e.g., Pea & Kurland, in press). These stand apart from a second set of symbol systems: Those which constitute the content of particular software or program. Thus the 'stuff' or content of a computer encounter can include visual designs, musical composition, various kinds of charts, maps, and geometric forms, as well as further linguistic or mathematical codes themselves. Indeed, in view of the wide variety of materials which can be presented on the cathode ray tube, there may ultimately be fewer biases in computers than has been the case with earlier media of communication. However, except for the most user-friendly software, the price of admission for use of computers apparently entails considerable linguistic and logical-mathematical sophistication.

Thus, the contemporary micro-computer offers a rich

playing field for the cultivation of a variety of symbolic skills. In addition to training in language and in logical-mathematics, there is the opportunity to gain competence with the various symbol systems which constitute the 'content' of programs. Moreover, in many cases, the computer can provide ready-made symbolic entities of a high degree of complexity; such provision short-circuits the efforts needed to make a drawing, compose a song, write a story "from scratch," and enables the user to enter in medias medium.

But most importantly, it is also possible to provide programs in which children construct these building blocks for themselves. Thus the computer readily presents information reflecting different levels of completion, allowing a user to construct entities by himself or herself, on the one hand, or to by-pass these often difficult or time-consuming constructive processes on the other. The opportunities for cultivation of skills, on the one hand, or for supplanting or short-circuiting them on the other, far exceed those of earlier media.

Indeed, computer afforded interactive activities become of particular interest to educational researchers to the extent that they can be expected to exert influence on learners' cognitive operations and through them, on learners' knowledge structures. Quite possibly, operations that are associated with symbolic representation may differ from the

ones that are typically associated with symbolic manipulation: the former are required for learning-by-being-told or shown whereas the latter typically entail learning-by-actual-doing. Decoding the visual presentation of an object's 3-D rotation on a CRT may well require different skills than programming its rotation.

Despite the wealth of educational opportunities afforded by computational encounters, our earlier survey cautions against the assumption that all of these opportunities will necessarily be seized, or skills acquired, simply because they are inherent or potentially present in the medium. Children are likely to bring their own prejudices and biases to the computer, as well as their own expectations about how much effort to invest; these in turn are likely to color the uses to which computers are put and the abilities which are likely to be cultivated. To put it in current social-psychological terms, whether the child approaches the computer in a mindful or mindless way is likely to make a decisive difference. Genuine differences in 'pre-computing' symbolic skills will also affect how computers are used and what lessons are learned. In some cases, it can be expected, these pre-existing skills will aid the subject in the mastery of computer; but it is also possible that these earlier evolved skills may interfere with computer facility, particularly when the earlier skills have been implemented in ways different from those required by the current technology.

It is no accident that many skilled writers have resisted even so simple a mode of technology as a word processor.

Armed with the results of our inquiry, we should revisit our original query. Certainly any question as simple as "How do computers affect children?," or "What do children learn from the micro-computer?" is unlikely to admit of a clear-cut answer. We must consider the kind of computational hardware and software at issue, the nature of the Subject, the subject matter, and the particular kinds of skills, operations or educational lessons which are pre-supposed as well as those that become actually involved. From our own perspective, insight is more likely to be obtained if one turns one's focus away from the medium or technology itself: the use of computers per se tells us little. Instead, it seems productive to attend to the particular symbolic systems used as a means of communicating with the machine; the particular symbol systems which constitute the contents of specific programs; the particular symbol-using skills which the user possesses prior to his or her encounter with the computer; and the way in which particular symbolic skills are taught, cultivated, altered or supplanted in the course of a more-or-less active computational encounter.

Our approach does not contain any simple recipe for research on children and computers: In fact one lesson of our survey is that such simple recipes are destined to be

misleading if not completely illusory. What we do have is a conceptual framework -- the symbol systems approach -- and a set of questions and issues which ought to be relevant to nearly any educational issue involving children and computers. Moreover, even as we recognize that computer technology is changing rapidly, we believe that this approach is sufficiently flexible so as to be relevant even if the shape of the technological landscape proves quite different a few years from now. This framework will not dictate an experimental design nor a method of analysis, but it will suggest the kinds of questions that one ought to be posing about computers, their symbol systems, their subject matter, the skills of the Subject, and the goals of the computational encounter. Certainly a more complex equation will result, should this nested set of questions be substituted for the beguilingly simple one stated at the beginning of this essay. But the result of this questioning process should be a more veridical notion of just what happens when a Subject and a microcomputer encounter one another.

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